

# SIMULATING THE HIGH-REDSHIFT UNIVERSE IN THE SUB-MM

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**Abstract** I present various simulations of an on-going large sub-mm survey, *SHADES*, showing how constraints can be put on galaxy formation models and cosmology from this survey.

**Keywords:** galaxy formation, large-scale structure, cosmology

## 1. Introduction

An important problem with most current galaxy formation models is how to establish whether a set of model parameters that produces a good match to observations is unique, as there are likely to be degeneracies amongst the various free parameters of the model. As most useful observational data used to constrain the model parameters are obtained from our local universe, this ‘uniqueness problem’ can be resolved by comparing model predictions and observations at high redshift, which in many respects is independent from a comparison at low redshift. Specifically, the *SCUBA* half-degree extra-galactic survey (*SHADES* for short; see <http://www.roe.ac.uk/ifa/shades> for details) will provide highly valuable observational data for this purpose.

## 2. A new wide-area sub-mm survey: *SHADES*

*SHADES* is a major new extragalactic survey with *SCUBA*, the “Submillimetre Common-User Bolometer Array” (Holland et al. 1999), covering 0.5 sq. degrees to a  $4\sigma$  detection limit of  $S_{850} = 8$  mJy. The data from *SCUBA* will be supplemented with data from *BLAST*, a “Balloon-borne Large-Aperture Sub-millimeter Telescope” (Devlin 2001), which will undertake a series of nested extragalactic surveys at 250, 350 and 500  $\mu$ m.

This wide-area survey will yield a substantial ( $\simeq 200$ ) sample of bright unconfused sub-mm sources with meaningful redshift estimates ( $\delta z \simeq \pm 0.5$ ). The survey is designed to answer three fundamental questions. What is the cosmic history of massive dust-enshrouded star-formation activity ? Are SCUBA sources the progenitors of present-day massive ellipticals ? What fraction of SCUBA sources harbour a dust-obscured AGN ?

The crude but near-complete redshift information provided by *BLAST* is sufficient to answer the second question provided the survey covers sufficient area and contains enough sources to measure the clustering of bright sub-mm sources on scales up to  $\simeq 10$  Mpc.

### 3. Modelling the high-redshift sub-mm population

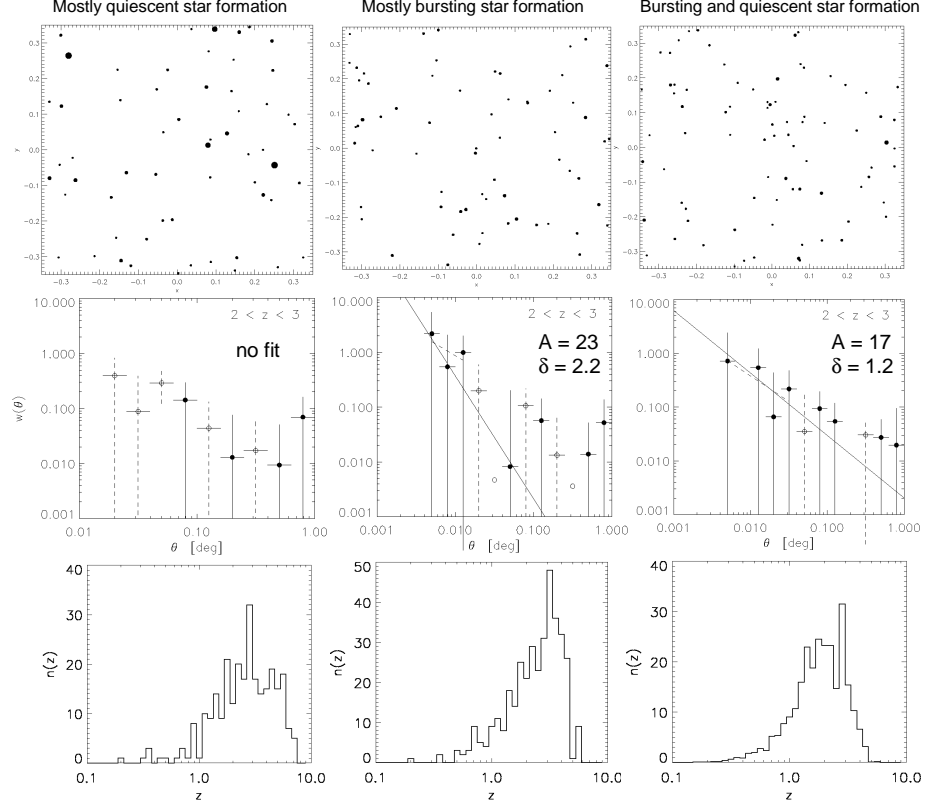
The assumption made here is that the bright sub-mm sources seen by *SCUBA* are dust-enshrouded starburst galaxies, as most show no direct evidence for AGN activity (Almaini et al. 2003). Simulating *SHADES* is thus best done using a phenomenological galaxy formation model, from which lightcones are constructed for all galaxies with an  $850\ \mu\text{m}$  flux over 8 mJy.

The merging history of galaxy haloes is taken directly from N-body simulations, which use special techniques to prevent galaxy-scale haloes undergoing ‘overmerging’ owing to inadequate numerical resolution (van Kampen 1995). When haloes merge, a criterion based on dynamical friction is used to decide how many galaxies exist in the newly merged halo. The most massive of those galaxies becomes the single central galaxy to which gas can cool, while the others become its satellites.

When a halo first forms, it is assumed to have an isothermal-sphere density profile. A fraction  $\Omega_b/\Omega$  of this is in the form of gas at the virial temperature, which can cool to form stars within a single galaxy at the centre of the halo. Energy output from supernovae reheats some of the cooled gas back to the hot phase. Each halo maintains an internal account of the amounts of gas being transferred between the two phases, consumed by the formation of stars, and lost to the environment.

The model includes two modes of star formation: quiescent star formation in disks, and starbursts during merger events. The evolution of the metals is followed, because the cooling of the hot gas depends on metal content, and a stellar population of high metallicity will be much redder than a low metallicity one of the same age. It is taken as established that the population of brown dwarfs makes a negligible contribution to the total stellar mass density, and the model does not allow an adjustable  $M/L$  ratio for the stellar population.

The  $850\ \mu\text{m}$  flux is assumed to be directly proportional to the star formation rate, with an 8 mJy flux corresponding to 1000 solar masses per year. The relation is taken to be fuzzy, so that a random amount of flux (amounting to about



*Figure 1.* The three columns of panels represent results from three different galaxy formation models, which mainly differ in how stars form (as indicated at the top). The top row shows a single realization of a mock *SHADES*, with the size of the dots corresponding to the flux of each source. The middle row shows the angular correlation functions for these maps, whereas the bottom row displays the redshift distribution of the sources. Differences in these predictions can be clearly observed.

25 per cent) is added/subtracted to reflect differences in dust temperatures and grain sizes which are not yet modelled.

#### 4. Predictions for three different models

Using the phenomenological galaxy formation model described above, three different mock sub-mm surveys resembling *SHADES* were produced. These models only differ in their star formation laws, in that one model has most stars forming quiescently in disks, one has most stars forming in merger-induced starbursts, and the remaining model has a mix of both. The resulting maps and predictions for the angular clustering and redshift distribution are shown in Fig. 1.

While the number counts are similar (not shown), the clustering properties, and to a lesser extent the redshift distributions, are clearly different for these realizations. It seems that the clustering strength depends on which star formation mode dominates, with the burst model yielding relatively strong clustering, and the quiescent model showing very little clustering. It has to be noted that there is a fairly large spread in predicted clustering strengths for different realizations of the *same model*, mainly due to cosmic variance. Still, the trend remains visible after considering 50 realizations for each model. The way forward is to make optimal use of combining the difference in the clustering *and* the redshift distribution. This work is currently in progress (van Kampen et al. 2003).

## 5. Conclusions and discussion

The on-going large sub-mm survey *SHADES* has the potential to put significant constraints on galaxy formation models, and help resolve the uniqueness problem of such models due to the uncertainties in the assumptions, approximations, and choice of parameters. A potential problem is that of cosmic variance: even though *SHADES* is the largest extragalactic survey ever undertaken in the sub-mm waveband, the total sky coverage is still much smaller than typically achieved in the optical wavebands. However, two factors work in our favour: the availability of (crude) redshift estimates for each of the sources, and the expectation that clustering of bright sub-mm galaxies is relatively strong (e.g. Percival et al. 2003, Scott et al. 2003, Webb et al. 2003, van Kampen et al. 2003).

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